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INTRODUCTION

The earliest record in Australia of stimulation of Pinus radiata by inoculation with mycorrhiza fungi was by Kessel (1923), in Western Australia. Since then it has become common nursery practice in Australia to introduce roots or litter from established forests into nursery beds to ensure the presence of mycorrhiza fungi. Such techniques may introduce pathogens or other deleterious organisms (Bowen and Rovira 1961) or only poorly efficient mycorrhiza types such as those indicated by the studies of Moser (1956), Levisohn (1957) and Bowen (1962 in preparation) but there has been no study in Australia of the natural occurrence of mycorrhiza fungi for P. radiata the most important softwood plantation species in southern and south-western Australia. Samuel (1926) recorded sporadic mycorrhiza formation on P. radiata in some recently cleared South Australian soils without inoculation.

Because of the wide distribution of trees with mycorrhiza in the north temperate zone, especially in Europe, and the apparent lack of specificity in the mycorrhiza associations, Harley (1959) concluded that potential mycorrhiza fungi are likely to be available as spores for almost all host trees. There has been little study however of the ability of mycorrhizal fungi to infect both the exotic trees and the Australian indigenous flora. On present knowledge of mycorrhiza fungi for Eucalyptus spp. (Table 1) only one, Pisolithus tinctorius forms mycorrhizas on Pinus spp; Bryan and Zak (1961) having reported mycorrhiza formation with it on Pinus echinata (but not P. taeda or P. ellistii var. elliotii). Neumann (1959) found that whereas P. tinctorius often produced a thick weft on roots of Eucalyptus camaldulensis and stimulated the plant, infection was rare. It is unwise to assume that in Australia, as in Europe, mycorrhiza fungi for Pinus spp. are freely available to new plantings. Indeed, Kelley (1950) documented responses to inoculation of Pinus spp. in Western Australia and Queensland as well as in Rhodesia, Nyassaland, New Zealand and Iowa; but such responses do not necessarily mean the complete absence of mycorrhiza fungi in the soil as inoculation may have introduced a more efficient strain.

The study reported here was of the natural occurrence of mycorrhiza fungi for P. radiata in South Australia and forms part of a larger investigation of the ecology, and physiology of the mycorrhiza condition of this species.

MATERIALS AND METHODS

a. Soils: Soils were collected from 78 sites in South Australia to include different soil types, different vegetation and a series at varying distances from an established pine forest.

Collection was made by pressing a cylindrical tin 7" deep and 7" in diameter into soil after removal of the surface inch. The tin was immediately covered by plastic sheet, during transport to the glasshouse. The tins and all tools used were sterilized with 70% ethyl alcohol before each sampling.

b. Glasshouse procedure: Seed of P. radiata surface sterilized for 20 minutes in a 1 : 1 mixture of ethyl alcohol and 20 vol. hydrogen peroxide followed by several washings in sterile water were planted in duplicate pots. One of these were inoculated with mycorrhiza roots from an established P. radiata forest at Second Valley, S.A. while the other remained untreated. Both were covered with sterile gravel to reduce dust and splash contamination from other pots. Over the nine months growth period watering was carried out with distilled water.

RESULTS

The roots in both inoculated and uninoculated pots were examined for the presence of typical forked mycorrhizas which occur with P. radiata. In all instances inoculated plants bore mycorrhiza indicating that soil and growth conditions were suitable for mycorrhiza formation. In many instances plant growth was decreased by inoculation and signs of root disease were observed. Isolation of potential root pathogens from Second Valley soils by the author suggests that plant pathogens may have been introduced with the inoculum - a major risk involved with the common forestry practice of introduction of mycorrhiza fungi by crude inocula. Such occasional decreases precluded a true assessment of plant response to inoculation although a stimulation was noted in some instances.

The absence of mycorrhiza formation in sterilized uninoculated soils and their absence also from pots placed adjacent to soils producing profuse mycorrhiza incidence confirmed that little, if any contamination occurred.

Mycorrhizas produced were of two general types; (i) "brown" in which the mycelial weft surrounding the root was poorly developed although other mycorrhiza features were present i.e. a well developed Hartig net and the absence of intracellular infection, and (ii) "white" in which a white external mycelial weft was well developed as well as the Hartig net.

The incidence of mycorrhiza formation of these two types and vegetation data are presented in Table 2. Figure 1 indicates the location of the sites and mycorrhiza incidence.

DISCUSSION

Of the 78 samples, 25 did not produce mycorrhizas and of the 53 which did, 27 were in areas near established forests or scattered plantings of P. radiata (mostly within one mile) The remaining 26 which produced mycorrhizas were all distant from pine trees and it may be concluded that mycorrhiza fungi for P. radiata occurred naturally in some 50 per cent. of samples well removed from introduced species of Pinus, or that spores were dispersed by wind. However mycorrhiza formation was sparse in approximately half of these (12 out of 26) and at least in some cases an interpretation of this as a reflection of low population of mycorrhizal fungi rather than of the particular soil conditions seems more satisfactory.

Examination of the mycorrhiza types present shows that 21 of the 53 soils producing mycorrhizas produced only the brown type described above. Of the 32 also producing the white type with a well developed mantle 20 came from sites in close proximity to pine plantings. This suggests that the dominant mycorrhiza fungus occurring naturally is one producing the brown type, the more typical white type being spread from established pine plantations. Further study on the ecology of mycorrhiza fungi substantiated by isolations is needed to prove this; but it is of particular interest that the brown type is most commonly encountered in South Australian P. radiata forests. Studies by the author (Bowen 1962 in preparation) indicate a much lower efficiency in phosphate uptake by this type than those with well developed mantles and they are potentially less efficient in tree stimulation. Whether this is actually so in the field will depend on the factors limiting tree growth in a particular situation. The frequent lack or sparsity of mycorrhiza fungi in natural soils and the potentially lower efficiency in nutrient uptake are points to recommend inoculation of nurseries with selected fungus strains.

Twenty five soils did not produce mycorrhizas and of these six were treeless, nine were under grass with widely scattered Eucalyptus and ten in areas under eucalypts as the main vegetation. The incidence of mycorrhiza in relation to existing vegetation (for areas further than an arbitarily selected 1.5 miles from existing pine trees are given in Table 3.

The data suggests naturally occurring mycorrhiza fungi for P. radiata to be frequently associated with species of Eucalyptus, while grass did not materially aid the establishment of the fungi. It should be recognized that the P. radiata mycorrhiza fungi possibly associating with or being stimulated by Eucalyptus species may not form mycorrhizas with eucalypts, the rhizosphere stimulation of Pisolithus tinctorius by E. camaldulensis with infection rare (Neumann 1959) being a marked example. The sparsity of mycorrhiza fungi in grasslands confirms the results of Wilde (1954) and Goss (1960) in the U.S.A. The evidence is not sufficient to postulate a toxic effect of the grass on the fungi.

The frequent occurrence of P. radiata mycorrhiza fungi with Eucalyptus stands and the wide distribution of these makes the spread of mycorrhiza fungi from existing forests difficult to assess. On the basis of profusion of mycorrhizas and the assumption that the typical mycorrhiza with well developed wefts originated mainly from existing plantations, spread of fungi by spores in sufficient numbers for subsequent establishment can occur for at least one mile and in some cases up to two or more miles.

SUMMARY

Soils from 78 sites in South Australia were examined for the natural occurrence of mycorrhiza fungi for Pinus radiata. These occurred in some 50% of soils not in close proximity to pine plantations; but were frequently sparse and of a poorly efficient type. It is, suggested that naturally occurring mycorrhiza fungi for pine may frequently exist in association, not necessarily mycorrhizal, with Eucalyptus stands. There was a tendency for absence of mycorrhizal fungi from natural grasslands. Data on fungi causing mycorrhiza formation on Eucalyptus is assembled.

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TABLE 1.

MYCORRHIZA FORMATION ON EUCALYPTUS SPECIES

Authority	Eucalypt	Fungus	Test
Ashton (1956)	E. regnans	Cortinarius ochrareus	Synthesis in pure cultu
		C. radicatus	"
		Clitocybe australiana	"
		Mesophellia arenaria	"
		Agaricus xanthoderma (Syn. Psalliota xanthoderma)	"
		Naematoloma fasciculare (Syn. Hypholoma fasciculare)	"
Pryor 1956	E. dives E. pauciflora E. macrorhyncha E. robertsonii	Scleroderma flavidum	Inoculation
Smith & Pope 1934	Eucalyptus spp.	Pisolithus tinctorius (Syn. Polysacchum crassipes)	Observation of occasional infection- no synthesis attempted.
Neumann 1959	E. camaldulensis	"	
Rawlings 1951	Eucalyptus spp.	Lycoperdon perlatum* Scleroderma bovista*	-

*Listed as suspected or proven mycorrhiza formers on *Eucalyptus spp.* and *Pseudotsuga toxiplia* and *Lycoperdon perlatum* on *P. nigra* var. *calabrica* but no syntheses have been reported. *Scleroderma bovista* was proven as a mycorrhiza former on *P. radiata* by Birch (1937).

TABLE 2

NATURAL OCCURRENCE OF MYCORRHIZA FUNGI FOR PINUS RADIATA

Sample	Profusion of* Mycorrhizas	Mycorrhiza/ types	Location	Vegetation
1.	-		Clinton	wheat, treeless
2.	+++	b,w	Ardrossan	Eucalyptus spp. wild oats
3.	++	b,w	"	Eucalyptus
4.	-		Maitland	grass, widely scattered Eucalypts almost treeless
5.	-		Moonta	Eucalyptus
6.	+	b	Kadina	Acacia, Eucalyptus
7.	-		Bumbunga	grass, very scattered Eucalyptus
8.	-		Everard Central	grass, treeless
9.	-		Balaclava	grass, treeless
10.	+++	b	Owen	Eucalyptus
11.	+	b	Templers	grass, scattered Eucalyptus
12.	-		Sandy Creek	grass, scattered Eucalyptus
13.	+	b	Rosedale	wheat
14.	-		Rosedale	wheat, scattered Eucalyptus
15.	+++	b,w	Altona	Eucalyptus
16.	++	b,w	Tanunda	grass, treeless
17.	-		Tanunda	" "
18.	+	b,w	Gomersal	widely scattered Eucalyptus
19.	++	b,w	Tanunda	grass, scattered Acacia, Eucalyptus
20.	++	b	Keyneton	grass, scattered Eucalyptus

Sample	Profusion of* Mycorrhizas	Mycorrhiza† types	Location	Vegetation
21.	++	b	Sedan	Eucalyptus
22.	-		O'Halloran Hill	grass
23.	-		Morphett Vale	*grass (x 400 yds)
24.	++	b,w	Moana	wheat (x 0.5 mls)
25.	-		Aldinga	grass, scattered eucalyptus
26.	+	b	Second Valley	#Eucalyptus (xx 2 miles)
27.	-		Second Valley	Eucalyptus (xx 2.5 miles).
28.	-		Cape Jervis	grass
29.	++	b	Second Valley	grass Eucalyptus forest (xx 1.6 miles)
30.	++	b	Second Valley	Eucalyptus (xx 0.9 miles)
31.	+++	b	Second Valley	grass, scattered Eucalyptus (xx 0.4 miles)
32.	+	b	Second Valley	grass (xx 100 yds)
33.	++	b,w	Second Valley	Grass (xx 50 yds)
34.	++	b,w	Second Valley	Grass (xx 20 yds)
35.	+++	b,w	Second Valley	Grass (xx 50 yds)
36.	++	b,w	Second Valley	Grass (xx 50 yds)
37.	+++	b,w	Second Valley	Grass (xx 400 yds)
38.	-			Eucalyptus (xx 400 yds)
39.	+	b,w	Fleurieu Peninsula	grass clover (x 1 mile)
40.	+	b,w	"	Eucalyptus (x 1 mile)
41.	-		"	Eucalyptus (x 1.5 mile)
42.	++	b,w	Hindmarsh Valley	Eucalyptus (x 50 yds)

Sample	Profusion of* Mycorrhizas	Mycorrhiza≠ types	Location	Vegetation
43.	+	b	Hindmarsh Valley	Eucalyptus (x 300 yds)
44.	++	b,w	Moorlands	Eucalyptus, Callitris
45.	+	b	Moorlands	Eucalyptus
46.	-		Coonalpyn	"
47.	-		"	"
48.	-		Tintinara	Eucalyptus heath
49.	+	b	Keith	Eucalyptus, grass
50.	++	b,w	Brecon	Eucalyptus, grass
51.	+	b	Desert Camp	Eucalyptus
52.	++	b,w	Parthaway	Scattered Eucalyptus grass
53.	+	b	Naracoorte	grass (x 1 mile)
54.	++	b,w	Naracoorte	Eucalyptus (x 50 yds)
55.	++	b,w	Naracoorte	Eucalyptus (x 2.5 miles)
56.	+	b,w	Penola	Scattered Eucalyptus - grass (xx 4 miles)
57.	+	b,w	Penola	Eucalyptus (xx 0.5 miles)
58.	+++	b,w	Penola	Eucalyptus, grass (xx 50 yds)
59.	++	b,w	Tarpeena	Eucalyptus, grass (xx 1 mile)
60.	++	b,w	Tarpeena	Eucalyptus, grass (xx 1 mile)
61.	++	b,w	Mt. Gambier	Pasture (x 0.3 mls)
62.	+	w	Mt. Gambier	Pasture (x 50 yds)
63.	+	b,w	Glencoe	Pasture (xx 500 yds)
64.	+	b,w	Furner	Pasture (x 1.5 miles)
65.	-		Konetta	Scattered Eucalyptus and grass
66.	-		Conmurra	Scattered Eucalyptus and grass (x 2 miles)

Sample	Profusion of* Mycorrhizas	Mycorrhiza† types	Location	Vegetation
67.	+	b	Kingston	Eucalyptus, heath
68.	+	b	Kingston	Eucalyptus
69.	-		Coorong	Scattered Eucalyptus and heath
70.	+	b	Coorong	Eucalyptus
71.	+	b	Salt Creek	Dense Eucalyptus
72.	++	b,w	Salt Creek	Dense Eucalyptus
73.	+	b	Salt Creek	Acacia, scattered Eucalyptus
74.	-		Salt Creek	Eucalyptus
75.	++	b,w	Magrath Flat	Eucalyptus
76.	-		Meningie	Eucalyptus (x 30 yds
77.	-		Meningie	Eucalyptus Casuarina
78.	++	b,w	Tailem Bend	Callitris

* - = No mycorrhiza formation
+ = Sparse mycorrhiza formation
++ = Moderate mycorrhiza formation
+++ = Intense mycorrhiza formation

† b = brown type (see text)
w = white type (see text)

Distances in brackets indicates the distance from the nearest solitary pine trees (x) or plantations (xx).

TABLE 3

OCCURRENCE OF MYCORRHIZAS IN RELATION TO VEGETATION

Vegetation	No mycorrhiza	mycorrhiza
Grass and treeless	6	2
Grass with scattered *Eucalyptus*	8	6
Predominantly *Eucalyptus*	10	20

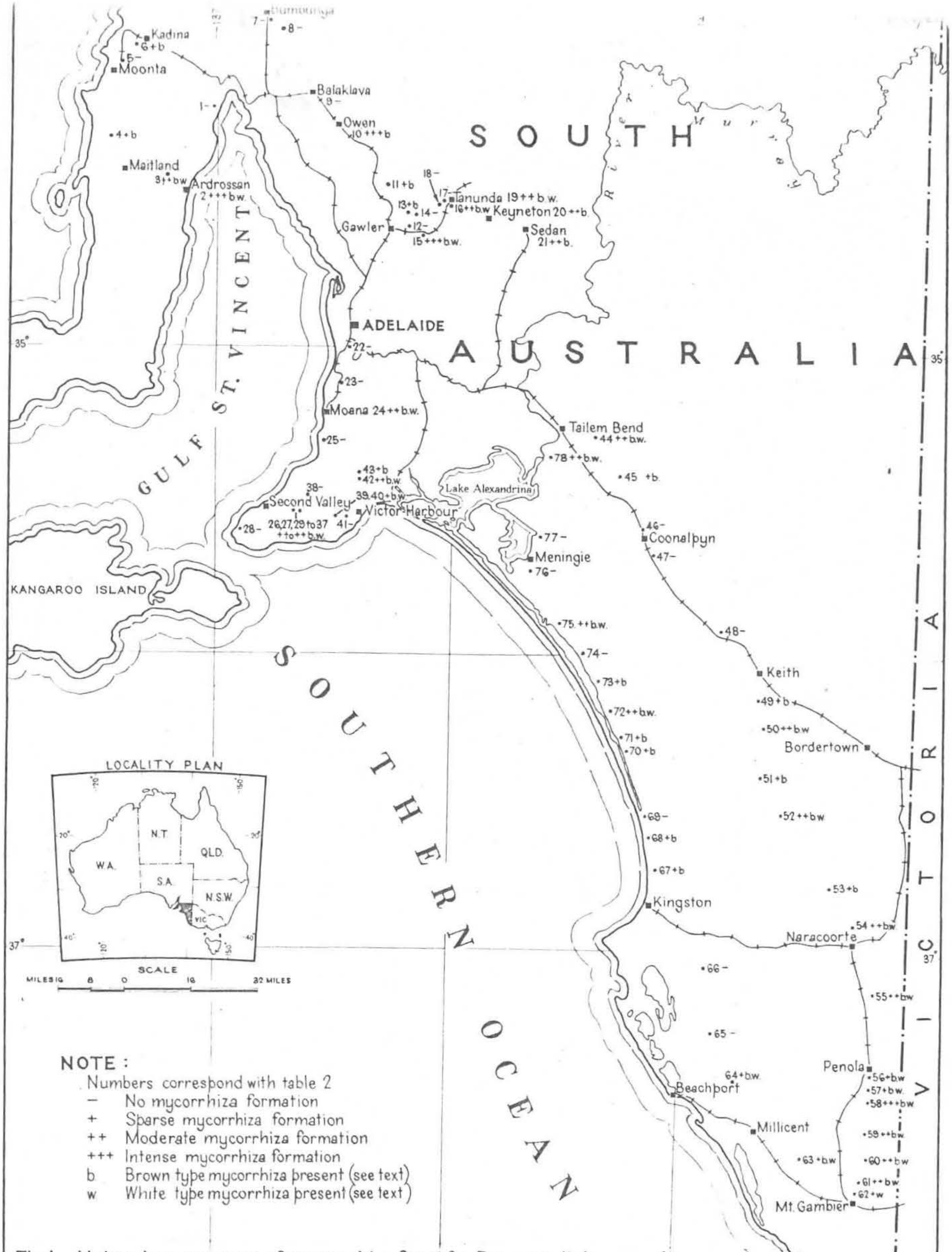

Fig 1. Natural occurrence of mycorrhiza fungi for Pinus radiata.